Demo Abstract : Real-Time Ambient Backscatter Demonstration

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***Abstract*—To lower power consumption and spectral congestion, it has been proposed to transmit digital informations by modulating the ambient electromagnetic waves emitted by different RF sources such as TV broadcast, Wifi. We have recently developed prototypes of backscatter tags and readers operating in real-time recycling DVB-T and 4G RF fields. They are small, flexible and for some of them autonomous in energy. Thanks to these devices, we show how the Binary Error Rate is correlated to the Power Contrast due to the backscatter modulation. Moreover, even in Line-Of-Sight configuration, the modulation efficiency strongly depends on the relative placement of the RF Source, Reader and the RF-Tag.**

I. Introduction

The population of connected objects or Internet-of-Things (IoT) is dramatically expanding and raises several challenges. First, a large number of connected objects must be self-powered. Secondly, though connected objects use very low data rate they still need to be spectral efficient as the spectrum resource is scarce. To overcome these two issues, a few years ago, Liu *et al.* [1] proposed a new communication system, called ambient backscatter, inspired by Stockman in 1948 [2] and Radio Frequency Identification (RFID) systems. In a classical communication, the transmitter emits and modulates an RF wave that is detected by a receiver. In the system proposed by Liu *et al.* [1], the transmitter (called tag) communicates with the receiver (called reader) without emitting any RF wave. An RF source of waves (such as TV broadcast) illuminates both the tag and the reader. The tag transmits information to the reader by electronically changing its own reflectivity at the symbol rate. In practice, it switches a metallic wire to make it resonating (or not) at the frequency of the source. By doing so, the tag modifies the level of scattering in the radio propagation channel between the reader and the source. To recover the transmitted message, the reader detects these fluctuations in the channel power. The RF tag communication circuit is ultra low power and can be powered by an RF energy harvesting circuit. In order to assess the performance of this system in terms of Bit Error Rate (BER), as a function of time, relative locations of the three elements, types of sources (TV, Wi-Fi and 4G) or propagation, we have developed small and flexible prototypes of tags and readers, communicating in real time.

Thanks to this versatile material setup, we show and demonstrate experimentally, in real time, that even when the tag, the source and the reader are in Line of Sight (LoS), the performance fades for some spatial relative configurations of the three elements. We also make real-time demonstrations with various sources.

II. Backscatter and reader prototypes

We have developed versatile prototypes of backscatter communication. For the purpose of live demonstrations, a tag based on MSP430 micro-controller either powered by a lithium battery or more by a solar cell (see Fig. 1a and [3]) has been built. The tag switches every 2.7 ms and sends a Frequency Modulation 0 (FM0) symbol every 5.4 ms (with a data rate of 185 bits/s). The tag loop-transmits 4 successive images of 88 bits encoded in FM0 (11x8 black and white pixels) of sprites (space invaders) and a 8-bit synchronisation sequence. The reader consists of a NooElec NESDR mini connected to a laptop or a Raspberry PI3, that runs an energy level comparator implemented under GNU Radio [4], an open-source software defined radio (SDR). Thanks to this transportable set-up (not connected to the eletric network), the backscatter communication has been tested in various environments such as high speed train (see Fig. 1c and [5]), underground , or indoor [6] (with TV tag-reader distance of around 5 meters) and for different sources, such as TV (500-700 MHz), Wi-Fi (2.4 GHz) and 4G downlink bands (778-788, 791-801, 801-811 and 811-820 MHz) (see Fig. 1b and [7]).

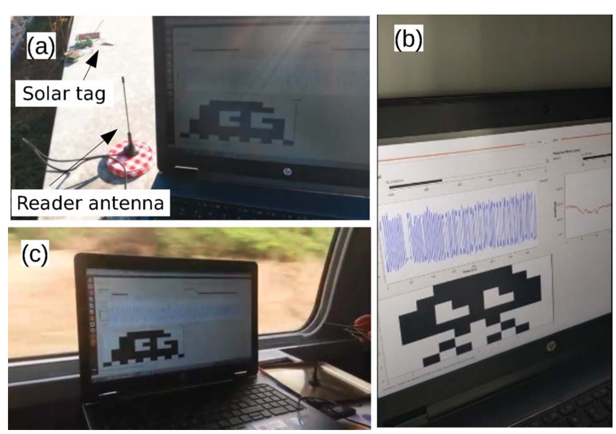

Figure 1. Photos of (a) Sun-powered TV backscatter (b) 4G backscatter (c) TV backscatter on board of a Paris-to-Lyon high speed train,

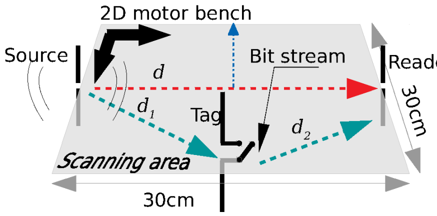

Figure 2. Configuration to measure the spatial dependancy of PC and BER with respect to the relative position of the source, reader and tag. The BER and PC shown on Fig. 3a have been measured on the blue dash-dotted line. The PC shown in Figs. 3b-d have been recorded in the 30cmx30cm squared area.

To study the performance of the backscatter communication system with respect to the relative positions of the three elements, we have developed another tag with an ATmega328 - Arduino, and another reader consisting of an USRP-B210 connected to a laptop, still using the energy detector.

III. Spatial performance

As metrics, we use the BER and we introduce the relative power contrast (PC) that is equivalent to the modulation index for classical amplitude modulation. The PC directly impact the BER. Indeed, $\mathrm{BER} = 0.5\mathrm{erfc}(\eta/\zeta)$ where η is the PC and ζ the signal to noise ratio. To scan both BER and PC, the tag is mounted on two translation stepping motors (see Fig. 2). Moreover, to control the position of the source, the ambient source is replaced by a controlled dipole generating RF noise connected to a USRP-B210. To study a configuration near to line-of-sight, some absorbing elements can be placed around the setup in order to mitigate reflections. In Fig. 3a the distribution of BER is plotted for different positions of the tag. The BER is assessed from the transmission of 2000 bits. Despite this LoS configuration, we observe strong fluctuations and fades of the BER. Note that the simple BER model based on PC fits very well the experimental BER (see inner plot in Fig. 3a). In order to have a better knowledge of the BER fading patterns, three 2D-scans of PC have been performed at 3 different working frequencies (see Figs. 3b-d): corresponding to Wi-Fi (2.4 GHz and 5.2 GHz) and future 5G (3.5 GHz). To interpret this results, we propose a simple scattering model. The field recorded by the reader is the superposition of the direct wave between the source and the reader and the wave that is backscattered. The complex field amplitude V_r^i is given by

$$V_r^i \propto \frac{1}{d} e^{jk_0 d} + \frac{f_i}{d_1 d_2} e^{jk_0(d_1+d_2)},$$

where i is either equal to 0 or 1 depending on the switch state. Distances d, d_1, d_2 are defined on Fig. 2. The complex numbers f_0 and f_1 are the scattering amplitudes of the resonator for the 2 states of the tag. For a resonant scatterer that is switched on (1) or off (0), $|f_0| < |f_1|$. From the previous equation, we note that the field at the reader location is constant when $d_1 + d_2$ is constant. As a consequence, PC patterns describes ellipsis where the foci are the positions of the source and the reader. We observe on Figs. 3b-d that the maxima and minima of PC are very well described by these ellipses. To overcome this strong fading effect, we are currently developing more advanced detection algorithms.

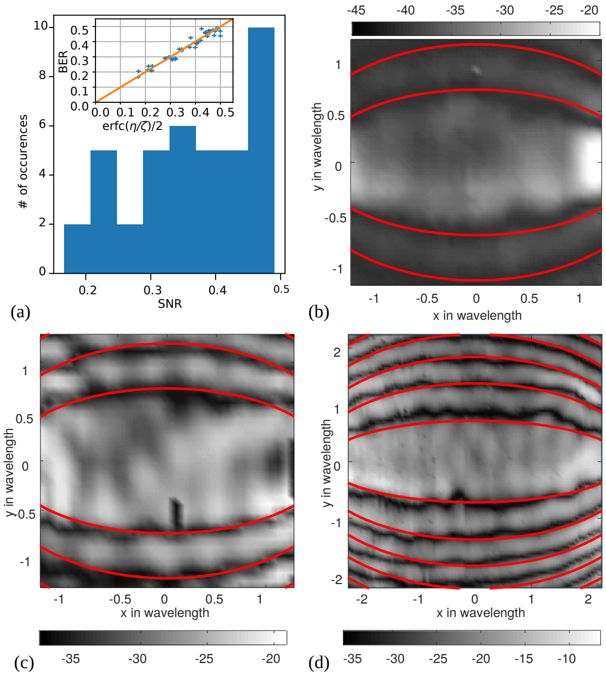

Figure 3. (a) Distribution of BER at 5.2 GHz when the tag is moved on a linear trajectory perpendicular to the line connecting the emitter and reader (see Fig. 2). Inner plot is the BER vs $\mathrm{BER} = 0.5\mathrm{erfc}(\eta/\zeta)$ (see text). Two dimensional scans of PC (dB scale) at 2.4 GHz (b), 3.5 GHz(c) and 5.2 GHz(d). The scanned squared area is shown on Fig. 2. The red lines are ellipsis where the foci are the locations of the emitter and reader.

IV. Live Demonstrations

We perform two live demonstrations using the versatile prototypes described in Sections II and III: 1) a real-time loop-transmission of 8 sprites with different sources (in TV or 4G bands) and a real-time spatial evaluation of the BER and PC metrics, with a tag moving along one axis.

V. Acknowledgment

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